

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A device for measuring the relative displacement between two members, the device comprising:

a scale having a scale grating pattern formed along a measuring axis direction; and

a fiber optic readhead arrangement positionable relative to the scale grating pattern to provide an operable interference illumination field arising from light diffracted by the scale grating pattern, the fiber optic readhead arrangement comprising:

a plurality of fiber-optic receiver channels, each respective fiber-optic receiver channel comprising:

a respective receiver channel spatial phase mask portion having a respective spatial phase and having its light-blocking elements arranged at a pitch that is operable for spatially filtering the light of the operable interference illumination field, the respective receiver channel spatial phase mask portion generally located at a nominal receiver plane that is operable for spatially filtering the light of the operable interference illumination field; and

at least one respective receiver channel optical fiber having an input end that receives a respective receiver channel optical signal light;

wherein:

the respective receiver channel optical signal light received by the at least one respective receiver channel optical fiber comprises optical signal light collected through the respective receiver channel spatial phase mask portion over a respective collected light area having a collected light area dimension along the measuring axis direction that is at least one full period of the respective receiver channel spatial phase mask portion;

when the readhead is operably positioned relative to the scale grating pattern at least first and second respective channels of the plurality of fiber-optic receiver channels spatially filter their respective portions of the light of the operable interference illumination field at the nominal receiver plane to provide at least first and second respective receiver channel optical signals having at least first and second respective signal phases; and

the device outputs the at least first and second respective receiver channel optical signals along respective optical fibers to provide relative displacement measurement information in the form of a plurality of respective optical output signals, the respective optical output signals produced without the use of an electronic photodetector element.

2. The device of Claim 1, wherein the fiber optic readhead arrangement comprises a transparent mask substrate and each respective receiver channel spatial phase mask portion is fabricated on a surface of the transparent mask substrate with its light-blocking elements positioned along the measuring axis direction with respect to the light-blocking elements of the other receiver channel spatial phase mask portions in a manner that establishes desired relationships between the respective spatial phases of the respective receiver channel spatial phase mask portions.

3. The device of Claim 2, wherein the input end of each respective receiver channel optical fiber is nominally positioned against the corresponding respective receiver channel spatial phase mask portion on the surface of the transparent mask substrate.

4. The device of Claim 1, wherein:  
the fiber optic readhead arrangement has an optical axis;  
each fiber-optic receiver channel has a respective nominal light-carrying area corresponding to an aggregate light-carrying core area of the at least one respective receiver channel optical fiber, the respective nominal light-carrying area proximate to the input end of the at least one respective receiver channel optical fiber having a respective nominal centroid; and

at least three respective fiber-optic receiver channels of the plurality of fiber-optic receiver channels each have a respective nominal centroid that is separated from the optical axis by a nominal respective location radius that is approximately the same for each of the at least three respective fiber-optic receiver channels.

5. The device of Claim 4, wherein:  
a central optical fiber is positioned approximately concentrically with the optical axis, at least proximate to an end of the central optical fiber, and the central optical fiber

comprises a single mode source optical fiber that emits radiation having an operable wavelength from a light-carrying core area at the end of the source optical fiber; and

the at least three respective fiber-optic receiver channels are positioned substantially against the central fiber at least proximate to the input ends of the respective receiver channel optical fibers and proximate to the end of the central optical fiber.

6. The device of Claim 1, wherein the plurality fiber-optic receiver channels comprise at least  $2N$  respective fiber-optic receiver channels arranged in an arrangement of  $N$  operable pairs, where  $N$  is an integer equal to at least 2, each operable pair comprising two respective fiber-optic receiver channels arranged on opposite sides of a center of the arrangement of  $N$  operable pairs, wherein the two respective spatial phase mask portions corresponding to those two respective fiber-optic receiver channels have one of a) the same spatial phase and b) spatial phases that nominally differ by 180 degrees.

7. The device of Claim 1, wherein at least each collected light area and each input end are positioned entirely within a cylindrical volume having an axis perpendicular to the nominal receiver plane and having a cylinder radius that is at most 3 millimeters.

8. The device of Claim 7, wherein the readhead arrangement has a cylinder radius containing at least each collected light area and input end which is at most 2.0 millimeters.

9. The device of Claim 8, wherein the cylinder radius containing at least each collected light area and input end is at most 1.25 millimeters.

10. The device of Claim 7, wherein the respective collected light area is at least partially determined by at least one of a) an aggregate light-carrying core area proximate to the input end of the corresponding at least one respective receiver channel optical fiber, b) a light receiving area of a miniature lens positioned proximate to the respective receiver channel spatial phase mask portion and proximate to the input end of the at least one respective receiver channel optical fiber and c) a limiting aperture feature of the respective receiver channel spatial phase mask portion.

11. The device of Claim 7, wherein the fiber optic readhead arrangement is designed such that for at least one operable position relative to the scale grating pattern, any light arising from the  $\pm 3^{\text{rd}}$  diffraction orders arising from the scale grating pattern falls outside of the cylinder radius at the nominal receiver plane.

12. The device of Claim 11, wherein the at least one operable position relative to the scale grating pattern corresponds to an operating gap of at most 5 millimeters.

13. The device of Claim 11, wherein the at least one operable position relative to the scale grating pattern corresponds to an operating gap of at most 2.5 millimeters.

14. The device of Claim 11, wherein the fiber optic readhead arrangement is designed such that any light potentially arising from the  $\pm 3^{\text{rd}}$  diffraction orders is evanescent.

15. The device of Claim 1, wherein a housing element surrounds the other elements of the fiber optic readhead arrangement, the housing element has a relatively longer outer dimension in a length direction parallel to the axis of the optical fibers and relatively narrower outer dimensions in directions perpendicular to the axis of the optical fibers over at least a portion of its length, and the fiber optic readhead arrangement is constructed such that at least a portion of the length of the housing element can be inserted into a bore having a dimension perpendicular to its central axis that is at least as small as 5.0 millimeters.

16. The device of Claim 15, wherein at least a portion of the length of the housing element can be inserted into a bore having a dimension perpendicular to its central axis that is at least as small as 2.5 millimeters.

17. The device of Claim 16, wherein the fiber optic readhead arrangement is assembled into an orientation-maintaining connector that is mechanically interchangeable with at least one standard commercially available polarization-maintaining optical fiber connector.

18. The device of Claim 1, wherein when there is relative displacement between the fiber optic readhead arrangement and scale grating pattern along the

measuring axis direction, each respective optical output signal comprises a sinusoidal function of the relative displacement, and each such sinusoidal function varies from an ideal sinusoidal function by at most 1/16 of the peak-to-peak variation of each such sinusoidal function.

19. The device of Claim 18, wherein each such sinusoidal function varies from an ideal sinusoidal function by at most 1/32 of the peak-to-peak variation of each such sinusoidal function.

20. The device of Claim 1, wherein the fiber optic readhead arrangement is located on a first side of the scale grating pattern, the scale grating pattern includes transparent elements that transmit transmitted light arising on a second side of the scale grating pattern, and the operable interference illumination field arises from transmitted light.

21. The device of Claim 1, wherein the fiber optic readhead arrangement is located entirely on a first side of the scale grating pattern, the scale grating pattern is at least partially reflective to reflect diffracted light arising on the first side of the scale grating pattern, and the operable interference illumination field arises from reflected diffracted light.

22. The device of Claim 1, wherein the fiber optic readhead arrangement includes at least one source of light, each respective source of light comprising one of a) an electronic solid-state light source element, at least a portion of the solid-state light source element generating the light, and b) an output end of a source optical fiber, the source optical fiber connectable to a remote light source that generates the light.

23. The device of Claim 1, wherein each respective collected light area has a collected light area dimension along the measuring axis direction that is at least three full periods of the respective receiver channel spatial phase mask portion.

24. The device of Claim 23, wherein each respective collected light area has a collected light area dimension along the measuring axis direction that is at least six full periods of the respective receiver channel spatial phase mask portion.

25. The device of Claim 1, further comprising a reflective surface, wherein:

the fiber optic readhead arrangement has an optical axis and the reflective surface is arranged at a location along the optical axis between the nominal receiver plane and the scale grating pattern such that the reflective surface effectively deflects the optical axis by approximately 90 degrees; and

the fiber optic readhead arrangement and reflective surface are arranged relative to the scale grating pattern such that the nominal receiver plane is nominally perpendicular to the plane of the scale grating pattern.

26. The device of Claim 1, wherein the scale comprises one of a) a generally planar member wherein the scale grating pattern is formed along a measuring axis direction that follows a straight line on the planar member, b) a generally planar disk-like member wherein the scale grating pattern is formed along a measuring axis direction that follows a circular path on the disk-like member, c) a generally cylindrical member wherein the scale grating pattern is formed along a measuring axis direction that follows a circular path around the cylindrical member, and d) a generally linear tape-like member wherein the scale grating pattern is formed along a measuring axis direction that follows a relatively longer axis of the tape-like member.

27. The device of Claim 1, wherein the fiber optic readhead arrangement is in a transmissive configuration such that the operable interference illumination field arises from transmitted light.

28. A method for operating a device for measuring the relative displacement between two members, the device comprising:

a scale having a scale grating pattern formed along a measuring axis direction; and

a fiber optic readhead arrangement positionable relative to the scale grating pattern to provide an operable interference illumination field arising from light diffracted by the scale grating pattern, the fiber optic readhead arrangement comprising:

a transparent mask substrate; and

a plurality of fiber-optic receiver channels, each respective fiber-optic receiver channel comprising:

a respective receiver channel spatial phase mask portion having a respective spatial phase and having its light-blocking elements arranged at a pitch that is operable for spatially filtering the light of the operable interference illumination field, the respective receiver channel spatial phase mask portion generally located at a nominal receiver plane that is operable for spatially filtering the light of the operable interference illumination field; and

at least one respective receiver channel optical fiber having an input end that receives a respective receiver channel optical signal light;

wherein:

each respective receiver channel spatial phase mask portion is fabricated on a surface of the transparent mask substrate with its light-blocking elements positioned along the measuring axis direction with respect to the light-blocking elements of the other receiver channel spatial phase mask portions in a manner that establishes desired relationships between the respective spatial phases of the respective receiver channel spatial phase mask portions;

the respective receiver channel optical signal light received by the at least one respective receiver channel optical fiber comprises light arising from the scale grating pattern and collected through the respective receiver channel spatial phase mask portion over a respective collected light area having a collected light area dimension along the measuring axis direction that is at least three full periods of the respective receiver channel spatial phase mask portion; and

at least each collected light area and each input end are positioned entirely within a cylindrical volume having an axis perpendicular to the nominal receiver plane and having a cylinder radius that is at most 5 millimeters;

the method comprising:

operably positioning the fiber optic readhead arrangement relative to the scale grating pattern;

receiving the light of the operable interference illumination field at the nominal receiver plane with at least first and second respective channels of the plurality of fiber-optic receiver channels and spatially filtering respective portions of the light of the operable interference illumination field to provide at least first and second respective

receiver channel optical signals having at least first and second respective signal phases;  
and

outputting the at least first and second respective receiver channel optical signals along respective optical fibers to provide relative displacement measurement information in the form of a plurality of respective optical output signals, the respective optical output signals arising from spatially filtered scale light without the use of an electronic photodetector element.

29. The method of Claim 28, wherein operably positioning the fiber optic readhead arrangement relative to the scale grating pattern comprises positioning the fiber optic readhead arrangement relative to the scale grating pattern such that any light arising from the  $\pm 3^{\text{rd}}$  diffraction orders arising from the scale grating pattern falls outside of each respective collected light area.

30. The method of Claim 29, wherein the operably positioned fiber optic readhead arrangement is located entirely on a first side of the scale grating pattern, the scale grating pattern reflects diffracted light arising on the first side of the scale grating pattern, and receiving the light of the operable interference illumination field at the nominal receiver plane comprises receiving reflected diffracted light arising on the first side of the scale grating pattern.

31. The device of Claim 30, the fiber optic readhead arrangement further comprising at least one respective source of light, the method further comprising emitting light from the fiber optic readhead arrangement to illuminate the scale grating pattern such that the reflected diffracted light arising on the first side of the scale grating pattern comprises light that is originally emitted from the fiber optic readhead arrangement.